Network Science CTA Overview

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NRC Report on Network Science

NRC Report on Network Science (2005)

Definition:

"*The fundamental components of a network are its structure (nodes and links) & its dynamics, which together specify the network's properties (functions & behaviors). Core research principles should enable predictions of network behaviors, given the structure & dynamics of the network as inputs*."

Overarching Conclusions

- Networks have a pervasive influence in all aspects of life
- Fundamental knowledge to predict properties of networks is primitive
- Research is fragmented with **disciplinary stovepipes**

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Network Science Challenges
Commercial vs Military Networks

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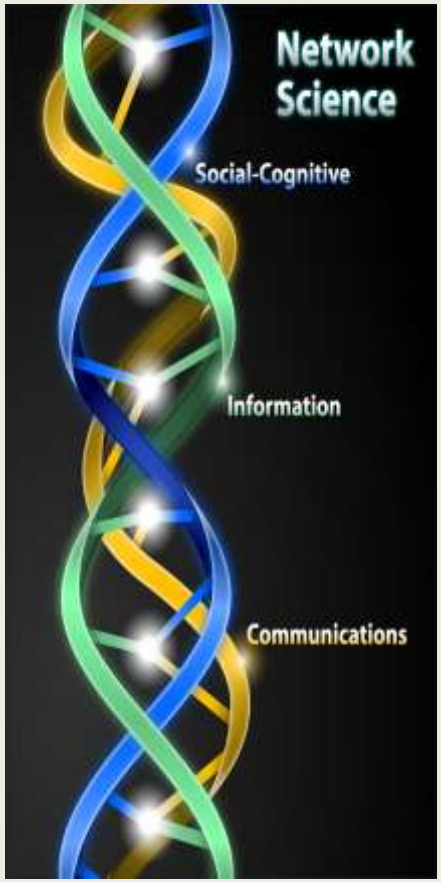
	Commercial	Military
 Communications	■ Fixed infrastructure ■ Resource-rich, stable ■ Limited security constraints ■ Interoperability by standards	■ Hybrid networks: Convergence of mobile ad hoc, cellular, fixed ■ Resource constrained, dynamic ■ High & multiple levels of security ■ Coalition interoperability
 Information	■ Google search, information apps rapidly evolving ■ Networks are open, benign, observable ■ Data mining & knowledge discovery tools	■ Search noisy, volatile, incomplete, untrustworthy, hidden, adversarial ■ Discovery of hidden attributes, semantic links, structures needed ■ Analytics of heterogeneous, noisy, dynamic, & adversarial nets
 Social-Cognitive	■ Pervasive social networking and content creation ■ Trusted social networking with friends & family ■ Stable, non-threatening social environment	■ Growing use of highly dynamic social networking ■ Potential subversion of network, challenged trust ■ Evolving, adversarial, social structures, influences, attitudes

Increased complexity of design, discovery, prediction, & control

Increased interactions between comms, information, & social networks

The Network Science Collaborative Technology Alliance

A Collaborative Venture between ARL, CERDEC, Academia, & Industry to create fundamental knowledge about complex multi-genre networks



NS CTA Objectives

- **Create knowledge & a fundamental understanding:**
  - Of interdependency, relations, & common underlying science
  - Among social-cognitive, information, & comms networks
- **Determine how processes in one network affect & are affected by those in other networks**
- **Develop approaches to prediction & control or influencing of the behaviors of these complex interacting networks**

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CTA Program Evolution

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Network Science CTA Awarded (2009)

- **Created by combining four separately-awarded consortia:** Interdisciplinary Research Center & three Academic Research Centers
- **EDIN** Cross-Cutting Research Issue (CCRI) created during initial planning process
- **Trust** CCRI created from proposed efforts in four Centers

Co-Evolving inter-genre networks (friendly & adversarial)

Co-Evolution & Dynamics of Inter-genre Networks

Information analytics to improve distributed decision making

Quality of Information for Semantically-Adaptive Networks

Multi-genre Networks

Information Processing Across Networks for Decision-Making

Controlling network behaviors to maximize relevant info delivery

Trust, Influencing, Modeling & Enhancing Human Performance

Social-cognitive phenomena to enhance human performance

- **Integrated Program since 2014:**
  - **Single Consortium**
  - **Focus on multi-genre networks, multi-disciplinary research thrusts**

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CTA Team

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Raytheon BBN Technologies

Northeastern University, Boston, Massachusetts

University of Southern California 1880

UC DAVIS UNIVERSITY OF CALIFORNIA

CUNY The City University of New York

Rensselaer Polytechnic Institute 1824 Rensselaer

PENNSTATE 1855

IBM

1867 ILLINOIS UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

University of California Santa Barbara

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Advancing Network Science

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Co-EDIN
- → Co-evolution & dynamics
- → Discovery, inference, & prediction
- → Controlling networks

QoI-SAN
- → Unified semantics
- → Pragmatics & constrained natural language
- → Semantic information delivery & capacity

IPAN
- → Context-aware analytics
- → Uncertainty management
- → Distributed processing for situational understanding

TIME
- → Trust in groups
- → Influencing multi-genre networks
- → Modeling social-cognitive dynamics

Fundamental theory of composite networks to predict & influence their co-evolution

Intelligent information delivery derived from context & intent of information requests that adapts to cognitive needs of decision makers

Embed cognitive & social context in information networks to enable comprehensive mission understanding

Revolutionary approaches for experimentation across network genres

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FY15-16 Biennial Program Plan

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Co-Evoluting Dynamic Inter-Genre Networks

C1: Modeling & Analysis of Groups in Multi-genre Networks

C2: Discovering Network Processes in Time-evolving Networks

C3: Learning & Prediction over Inter-genre, Time-evolving Networks

C4: Designing & Controlling Composite Networks

C5: Controllability of Complex Networks

Trust, Influence, Modeling, & Enhancing Human Performance

T1: Information-based Decision Making & Trust in Networks

T2: Social Dynamics, Opinion Spreading, & Influencing in Social Networks

T3: Trust, Influencing, & Enhancing Performance of Multi-genre Crowd Networks

T4: Cognition & Trust in Composite Networks

T5: Group Dynamics Emerge from Individuals: Scaling up Models of Cognition

Information Processing Across Networks for Decision-Making

I1: Constructing Unified, Structured Knowledge Networks

I2: Taming Uncertainty in Social Channels

I3: Resource-aware, Multi-modal Content Fusion

I4: Distributed, User-oriented Multi-scale Network Summarization & Online Analytical Processing

I5: Problem Solving in Socio-info. Networks

Quality of Information for Semantically-Adaptive Networks

Q1: Semantic Information Theory

Q2: Pragmatically-aware Quality of Information

Q3: Modeling & Analysis of Information Flow in Networks

Q4: Quality-aware Semantic Video Analytics

Q5: Semantic Quality-aware Information Delivery

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Leading the Field of Network Science

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Recently Established, Peer-Reviewed Journals

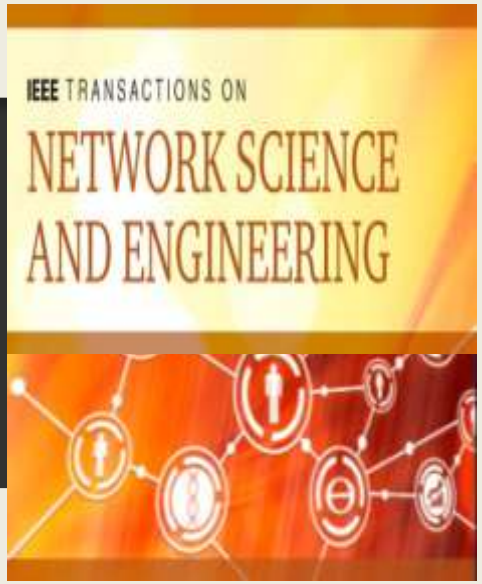
IEEE Transactions on Network Science & Engrg

Inaugural Issue Jan 2014, 5 issues published to date

Associate Editor: D'Souza (UC Davis)

Steering Committee: **Swami (ARL)**, Lin (IBM), Syzmanski (RPI)

Focus: **Theory & applications of network science & the interconnections among the elements in a system that form a network**




IEEE JOURNAL ON
SELECTED AREAS IN COMMUNICATIONS
A PUBLICATION OF THE IEEE COMMUNICATIONS SOCIETY
June 2013 VOLUME 31 NUMBER 6 ISACEM ISSN 0733-8716
NETWORK SCIENCE
P. Basu, R. Gibbens, T. La Porta, C.-Y. Lin, A. Swami, and E. Yeoki
IEEE

IEEE JSAC Special Issue on Network Science

June 2013 (Multi-Genre Emphasis)

Editors: Basu (BBN), **Swami (ARL)**, La Porta (PSU), Lin (IBM)

Authors: Abdelzaher, Aggarwal, C. Faloutsos, M. Faloutsos, Prakash, Ribeiro, Towsley, Valler, Wang, Wie, Zhao, **Kaplan (ARL), Swami (ARL)**

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Leading the Field of Network Science

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Recently Established, Peer-Reviewed Journals

Network Science: Cambridge University Press

Inaugural Issue April 2013, 9 issues published to date

Founding Editors: Adamic (Mich), Contractor (NWU), Vespignani (NEU), Wasserman (IU)

Associate Editors: Aral (NYU), C. Faloutsos (CMU), Lazer (NEU), Srivastava (UMN), Toroczkai (ND)

Focus: A new journal for a new discipline - one using the network paradigm, focusing on actors and relational linkages, to inform research, methodology, & applications from many fields across the natural, social, engineering & informational sciences.

Journal of Complex Networks: Oxford University Press

Inaugural Issue June 2013 2014, 9 issues published to date

Associate Editor: D'Souza (UC Davis)

Focus: Analysis & understanding of complex networks & its applications in diverse fields. Covers everything from the basic mathematical, physical & computational principles needed for studying complex networks to their applications leading to predictive models in molecular, biological, ecological, informational, engineering, social, technological & other systems.

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Recent NS CTA Books

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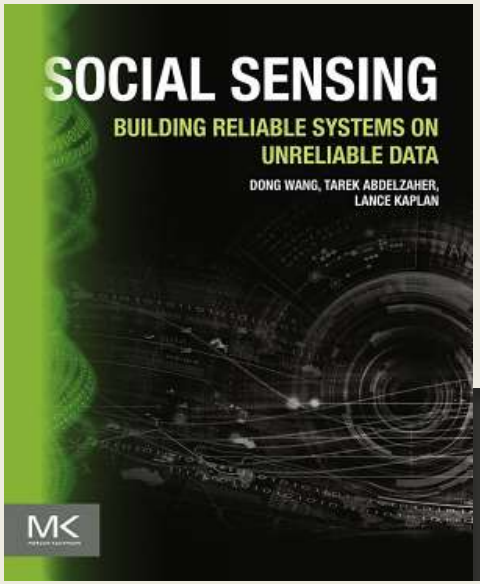


Increasingly, human beings are sensors engaging directly with the mobile Internet. Individuals can now share real-time experiences at an unprecedented scale.

Social Sensing: Building Reliable Systems on Unreliable Data **looks at recent advances in the emerging field of social sensing, emphasizing the key problem faced by application designers: how to extract reliable information from data collected from largely unknown and possibly unreliable sources.**

Social Sensing: Building Reliable Systems on Unreliable Data (April 2015)

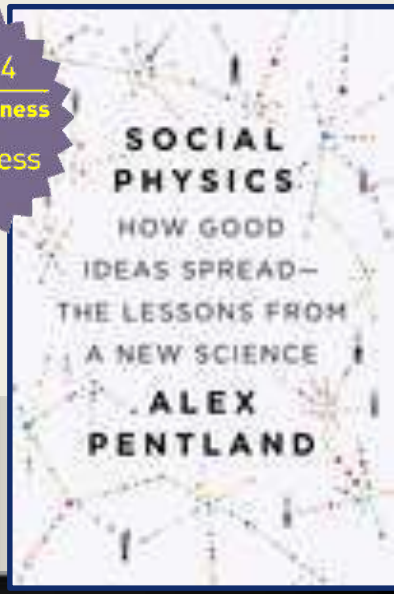
Authors: Dong Wang (Notre Dame),Tarek Abdelzaher (UIUC), **Lance Kaplan (ARL)**

"Social Physics is filled with rich findings about what makes people tick. Using millions of data points measured over a long period of time in real settings, which Pentland calls 'living laboratories,' the author has monitored human behavior on an unprecedented scale …

Social Physics is a fascinating look at a new field by one of its principal geeks."

— The Economist

2014 strategy+business Best Business Book



Social Physics: How Good Ideas Spread – The Lessons From a New Science (January 2014)

Author: Alex (Sandy) Pentland (MIT)

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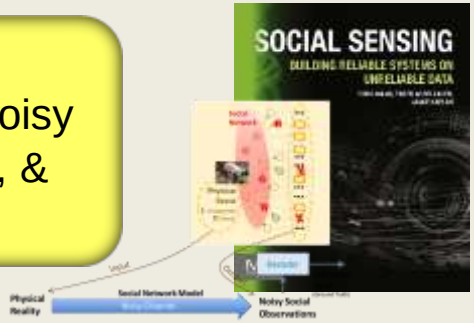
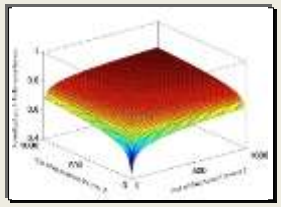
Key Recent Research Results

ARL

Developed a theory of reliable real-time social sensing for information extraction: By constructing models of social media as noisy communication channels, establishing fundamental bounds on accuracy, & developing real-time algorithms for reliable information extraction





Established fundamental limits on amount of communication for interactive function computation with non-common knowledge bases: Designed codebooks to minimize semantic distortion over noisy channels, in the presence of influencing agents (that may be adversarial)

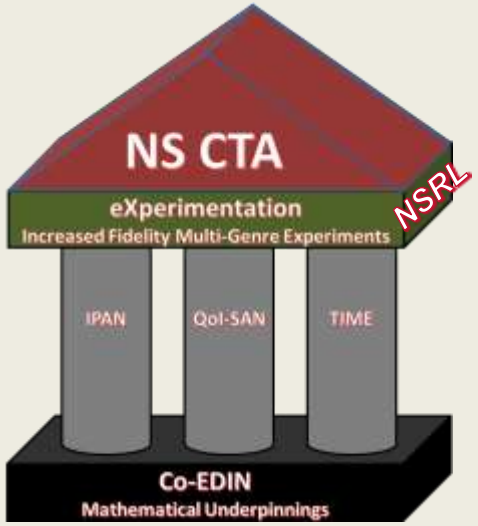
Developed game-theoretic & dynamic programming formulations of the network redesign problem under adversarial dynamics: Characterized & established conditions for pure & mixed Nash equilibria; myopic DP algorithm trades-off current optimality for long-term behavior

Obtained Insights on the co-evolution of opinion diffusion & social network: By developing theoretical models of opinion diffusion in dynamic social networks. Impact of cultural & structural properties validated on longitudinal data from a medium-scale network

NS CTA Multi-Genre Experimentation

Goals

- Advance insights and challenge hypotheses with ***integrated, cross-network experiments***, bringing together results from multiple tasks and thrusts
- Meet challenges in the ***science*** & ***practice*** of experimentation with new experiment and analysis methodologies, scenarios, & datasets
- Increase the ease, size, timescale, realism, & military relevance of experiments



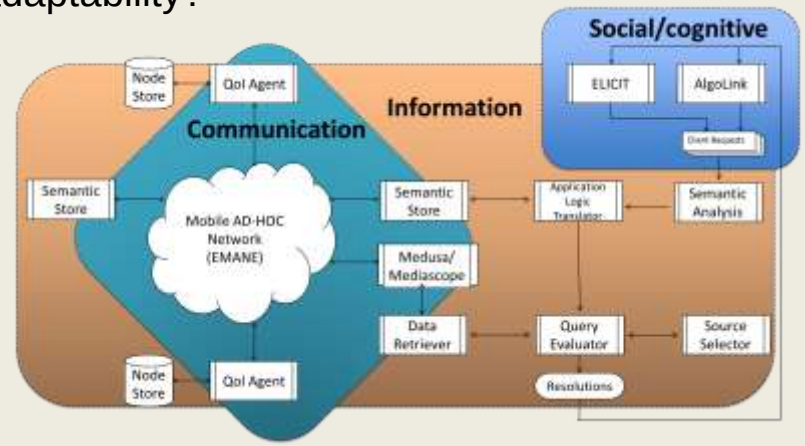
Approach

- New experimentation paradigms, methodologies, & designs that will increase the range of composite network science phenomena that can be experimentally studied
  - Experimentation methodologies to study multi-time scale cross-network interactions
  - Increasing experimental validity by understanding mapping outcomes across different contexts
- Explore & develop new concepts & re-usable capabilities for integrated, multi-genre networks science experimentation
  - Collaborative applied experiments in multi-genre networks to study, validate, & demonstrate basic research results in military relevant scenarios

NS CTA Experimentation Drives Fundamental NS Questions

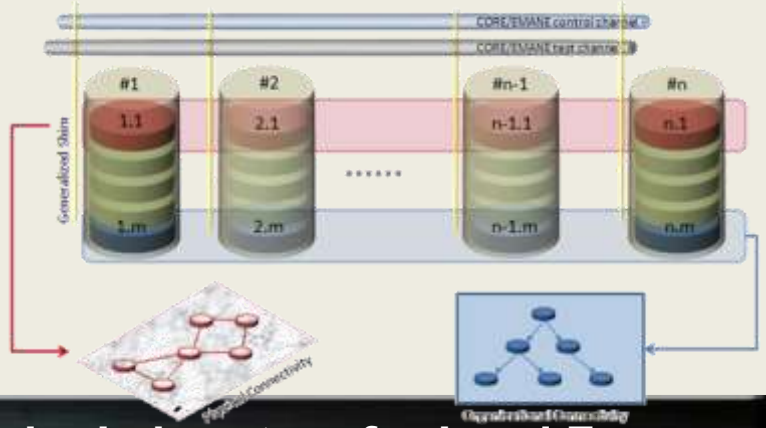
Robustness & Fragility:

- How can one network genre compensate for imperfections in another?
- How can we preserve performance under conditions of overload and loss?
- How to minimize the trade-offs necessary for adaptability?



Disruption & Recovery:

- What are the dynamics following a shock?
- How can coordination speed network recovery?
- What is the impact of disparate timescales on the dynamics of recovery?



Tipping Points & Cascades:

- What conditions accelerate evolution toward stable states and where are the critical thresholds?
- How do cross-genre interactions form feedback loops?
- Can network failure cascades be detected and reversed?

Advancing the science of multi-genre experimentation

1. Fundamental Research in Network Science Experimentation

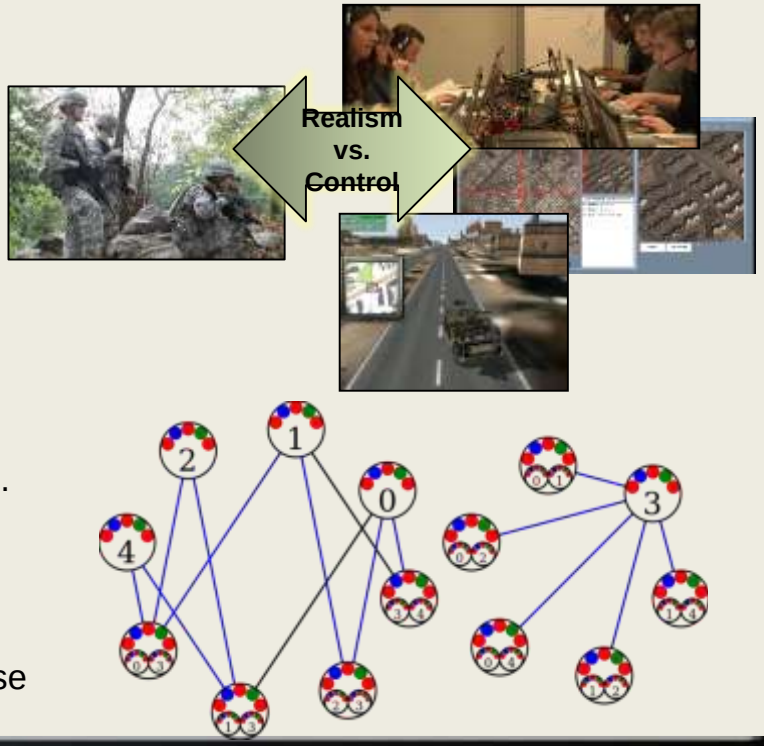
- **Validity, Realism, Range, & Control in Multi-Genre Network Experiments:**
  Explore multi-time scale cross-network interactions for hybrid human/simulation experiments and develop methodologies to i) enable timescale compression and extension in cross-network interactions, 2) increase network size to reduce edge effects and improve realism, and 3) develop generalized performance metrics. Develop techniques for mapping experimental results so that theories and conclusions can be generalized between contexts.

2. Applied Research in Network Science Experimentation

- **Realistically Finite and Heterogeneous Networks:**
  Develop mixed fidelity modeling & simulation capabilities to explore cross-network interactions & transmission propagation across realistically large networks.

- **Time Scales:**
  Explore interactions among network genres that cause feedback-based resonant or interference effects in each other, seek to understand causes, & develop mitigation and influence approaches.

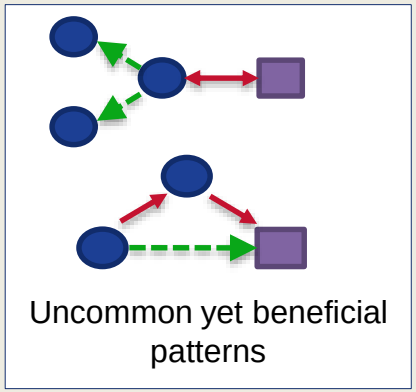
- **Network Tipping Points and Cascades:**
  Develop & validate cross genre activity models of how one genre may trigger significant change in others. Investigate large network parameter spaces to determine high sensitivity regimes where phase transitions occur.



Key Accomplishments

Teams-of-teams, communication, and uncertainty:

- **Result:** Specific inter- & intra-team interaction patterns explain 31% of variation in overall team-of-teams performance
  - The reactive gatekeeping and transitive representation are rare, but beneficial
  - Generalized boundary spanning and active personalize boundary spanning are common, but harmful
- **Integrated Experimentation Insight:** Relational Events Analysis (REA) is a powerful technique to understand causality in dynamic network interaction data.
- **Research Enabled:** Analysis of multi-genre, time-stamped interaction logs, spurring more detailed understanding of team effectiveness



Uncommon yet beneficial patterns

Cross-genre fragility and robustness:

- **Result:** A simple social cascade dampening policy enables successful communication at 50% of the bandwidth
- **Integrated Experimentation Insight:** Error at the mission level can drastically differ from error at the packet level; overall metrics are needed
- **Research Enabled:** Simulation exploration of cross-genre impact on mission-level effectiveness over limited communications networks

Crowd-sensing data source selection and prioritization:

- **Result:** By considering information and decision networks, sensor data source selection and prioritization schemes reduced decision time by 20% to 50%
- **Integrated Experimentation Insight:** Complementary simulation of abstracted and concrete mission scenarios can demonstrate applicability of research results
- **Research Enabled:** Exploration of a large mission parameter space for sensor network-aided decision-making

Summary

- We are advancing the state-of-the-art in Network Science
  - Multi-disciplinary research
  - Multi-genre (social/cognitive, information, and communications) networks
  - Experimentation
- Achievements enhanced by synergies gained from academia, industry, & government collaborations